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ABSTRACT

In the context of the discipline of quality control, this paper identifies many of the tools which may reinvigorate the statistical and graphical toolkits in higher education. Certain statistical and graphical issues are discussed by means of examples and hypothetical situations, and techniques are introduced that have application for the pursuit of total quality management and that draw upon confirmatory and exploratory data analysis. First, the paper considers the cause and effect diagram as a graphical technique for developing approaches to the subsequent gathering of data with respect to a given effect or outcome. Next the Pareto diagram, a tool for prioritizing or otherwise seeing the magnitude of various causes affecting an outcome is examined. A discussion of control charts follows naturally from a consideration of statistical thinking and the importance of understanding variation in the processes that provide opportunities for change. The concept of statistical control is introduced to aid in the handling of special-causes, common-causes and the subsequent system change. A later section briefly explores how some of these techniques may be applied to current university concerns such as student retention, application flow and yield and faculty allocation. The paper contains 6 graphs and 16 references. (JB)

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TOTAL QUALITY MANAGEMENT:

STATISTICS AND GRAPHICS

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Jean Endo
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TOTAL QUALITY MANAGEMENT: STATISTICS AND GRAPHICS

Abstract

When Lawrence Sherr spoke on "Is There a Better Way to Manage Higher Education?" at the 29th Annual AIR Forum and on "Quality in Higher Education - A Verb, Not a Noun" at the 30th Annual AIR Forum, the excitment he generated suggests that along with many of our goals and assumptions, we reinvigorate our statistical and graphical toolkits, particularly in the context of the discipline of quality control. This paper identifies many of these tools and provides examples of some of them including: Pareto diagrams, cause-and-effect diagrams and control charts.

INTRODUCTION

Lawrence Sherr in his speech, "Is There a Better Way to Manage Higher Education?" at the Twentieth-nineth AIR Forum two years ago, indicated, when he discussed W. Edward Deming's Fifth Point of his Fourteen, that we as institutional research practitioners need to reinvigorate our statistical and graphical toolkits. In fact, he asserts in Sherr (1989):

> Improve quality. Improve constantly and forever the system of production and service... This is where I think you folks fit in... I have found that as American businesses have awakened to this, they turn to people... for advice on how to manage their problems. Now, what we give them is new statistical tools. By the way, that's new to them, known to statisticians since 1930. In fact, ignored by most of us, not taught in business schools at all during the 60's and 70's and most of the 80's. Take a look at the textbooks and you will not find it in most of the textbooks today. These tools, I claim, you need to learn about. You need to find out what cause and effect fish bone diagrams are. You need to find out what Pareto charts are. You need to learn something about statistical variation when it's put in terms of a process rather than a static environment.

It is the purpose of this paper to discuss some of the statistical and graphical issues indicated by Sherr above and subsequently reemphasized in Sherr (1990). Only those portions of Deming's ideas that relate to these issues will be discussed here. Full discussions of Deming's ideas including his fourteen points for support of total quality management (TQM) occur in many places including Deming (1986) or Walton (1986).

In "Kaizen", Imai (1986, p. 239) gives us an initial look at the statistical and graphic tools that Sherr is alluding to above. They are given as the "Seven Statistical Tools" which are listed as: 1) Pareto diagrams; 2) Cause-and-effect diagrams; 3) Histograms; 4) Control charts; 5) Scatter diagrams; 6) Graphs; and 7) Checksheets. A second set is called the "New Seven" and is composed of: 1) Relations diagram; 2) Affinity diagram; 3) Tree diagram; 4) Matrix diagram; 5) Matrix data-analysis diagram; 6) Process Decision Program Chart (PDPC); and 7) Arrow diagram.

As would be expected different implementors of TQM choose to use other combinations of these tools. For example, see Gabor (1990, chap. 6) for the experience of Florida Power and Light or Coate (1990) for the choices made by Oregon State University - Corvallis. The three tools emphasized in this report are: cause-and-effect diagrams; Pareto (pah-ray-toe) diagrams; and control charts, since they are generally not found in the literature of institutional research. The "New Seven" will not be discussed suffice to say they are useful charts and diagrams to aid in the

understanding complex relationships and data collection.

Two examples from the TQM literature will be noted along with three examples using institutional research data. In addition, to the tools discussed, the concern that is implicit in Sherr's comments and the TQM literature is that "statistical thinking" is a cornerstone of the quality movement as promoted by W. Edward Deming. While his work and emphasis is in the tradition of Fisher and consequently confirmatory in nature, many of these tools are useful for exploratory analysis. See Bernard Yancey (1988) and his fellow authors in the recent book, "Applying Statistics in Institutional Research", for a discussion of the distinctions between these two approaches. They are both important components in the statistical toolkit of the insitutional researcher.

EXAMPLE 1: TELEPHONE WAITING TIME

The following case study is given by Masaaki Imai (1986, p. 54) which he reprinted from the Ricoh Company. It deals with the wait a bank customer experiences before a telephone call reaches the proper party. While it pertains to the handling of some 500 calls per day, it both illustrates some of the techniques we have listed above and it has direct application to many administrative offices in a college or university setting. The study was performed and the changes implemented by the staff directly involved in the process. It proceeded in the following manner: 1) They developed a theme for the project which was based on the

realization that the first impression a customer receives from a company is very important and an old rule to avoid needless switching from extension to extension; 2) A cause-and-effect diagram was created after a brain-storming session which listed the possible causes for delayed telephone calls (An example of the format of the graphic will appear later. It is sometimes called a fishbone diagram.); 3) a checklist was made of the reasons callers waited for more than five rings with a tally for each as they occurred over a few weeks; 4) the data recorded on the checksheet unexpectedly revealed that "one operator" topped the list as noted on the corresponding table of frequencies and Pareto diagram (An example of the format of the graphic will appear later. It appears as a histogram with a line graph attached to it.); 5) a goal was set of zero for the number of waiting callers, that is, all incoming calls would be handled promptly without inconveniencing the customer; 6) in order to accomplish it the staff decided to: a) take lunches on three different shifts leaving at least two operators on the job at all times by using a helper operator during the lunch hour, b) asking all employees to leave messages when unavailable for calls, and c) compiling a directory listing all personnel with areas of interest to customers; 7) a second tally was taken after the changes were and a second Pareto diagram was created with the result that although the waiting calls could not be reduced to zero, all items showed marked improvement.

In this case study, the Pareto diagrams helped to indicate the dominant causes for customer waits. This is one of its main uses to show via a bar graph in decending order, the causes that present a problem. A line graph gives a cumulative percentage of the problem that is helped as each cause is corrected. Also, a comparison of the "before" and "after" diagrams highlight the improvement. One can perform several graphical or statistical methods to show or otherwise indicate the differences in two or more Pareto diagrams. In addition, to "superimposing" the histograms, one can create a "demographic population pyramid" or Pareto pyramid as shown by Wadsworth, Stephens and Godfrey (1986, p. 309). Further, Kenett (1991) compares Pareto diagrams using an M-test which is stronger than the standard chi-square test which can also be used. Comparisons based on the above example might be made with a "standard" level of performance throughout the institution or perhaps only amongst several similar offices.

EXAMPLE 2: EXPERIMENT WITH RED BEADS

There is a simple experiment that Deming (1986, p. 346) frequently uses in his lectures; Walton (1988, chap. 4) dubs it "The Parable of the Red Beads". It has for equipment a box full of 750 (20%) red beads and 3,000 (80%) white beads along with a paddle with 50 beveled depressions for scooping 50 beads out of the box at one time. The beads are replaced and thoroughly mixed before each sample is taken. He creates a staff by finding six workers, two inspectors, a chief inspector, and a recorder in the

audience and plays the role of forman himself. He explains that their customer will accept only white beads. The work standards are 50 items per day, good and bad combined, for each worker. After an apprenticeship of three days (compressed into 10 minutes), each worker performs four days of work. The results are complied by the recorder after counts and recounts by the inspectors. We note that Worker A is praised the first day but "fails" the second. Worker C has trouble both days. On the third day, the foreman threatens to close the operation if the fourth day shows no improvement. Of course, since it doesn't, everyone is thrown out of a job. The results are summarized and shown as a control chart in Figure 1.

Deming then observes that in spite of training, understanding, and willingness on the part of the staff: 1) low yield was due to the incoming product; 2) variation arose from the system and not the workers; and 3) that the daily performance for each worker was unpredictable. He asserts the other experiments with the same beads, same paddle, same foreman, but different workers gave the same results thus indicating the the process was in statistical control. A process that is in statistical control furnishes a rational basis for the prediction of tomorrow's run. The next step in the improvement of this process would be to experiment with it. That is, both training and the paddle might be changed but until something more fundamental is done the results will remain essentially the same.

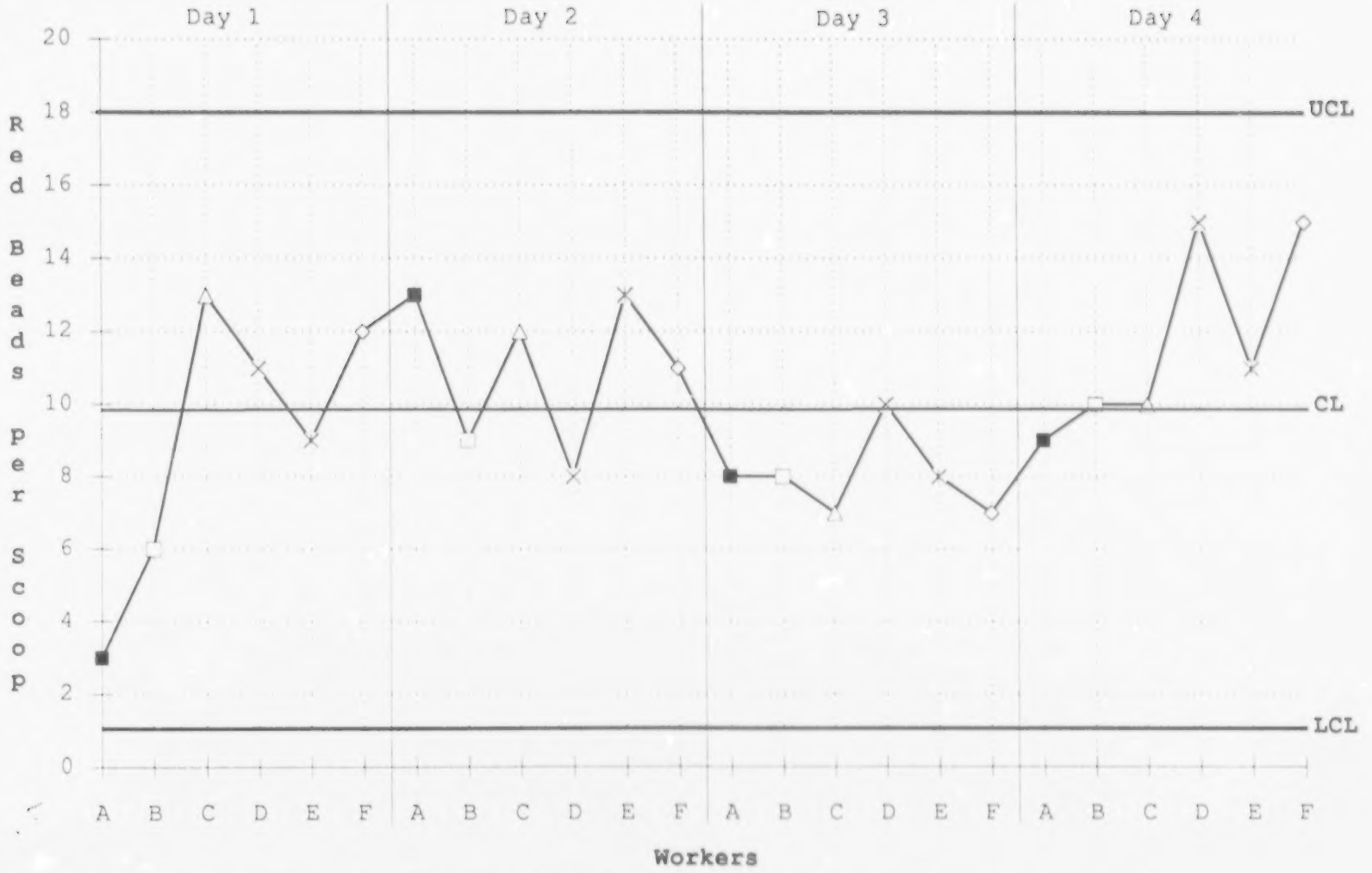

Figure 1 Experiment with Red Beads - Control Chart over a Four Day Period

STATISTICAL THINKING

In a recent article, Snee (1991) discusses the concept of statistical thinking which is consistent with and derives from the fundamental principle of quality put forth by W. Edwards Deming, that is, reduce variation and you improve quality. Statistical thinking recognizes that variation is all around us and present in everything we do, all work is a series of interconnected proceses which provide opportunities for improvement. By integrating ideas of process, variation, analysis, knowledge and action, we can participate in quality improvement.

Figure 2 portrays the two basic concepts: 1) eliminate the special causes of variation bringing the process into a state of statistical control and 2) improve the system by reducing the common causes of variation. One generally treats special-cause variation by finding its cause and creating solutions to prevent its recurrence. This relies on the use of problem-solving tools. The reduction of common-cause variation focuses on improving the system. It depends on a thorough knowledge of the system based on extensive study and the willingness to make the needed changes. Additionally, Snee (1991, p. 13) reminds us that Deming and his colleagues point out, most managers treat all problems as due to special-cause variation, that is, a problem to be fixed or a fire to fight. In fact, however, over 85% of all problems are due to defects in the system or common-cause variation.

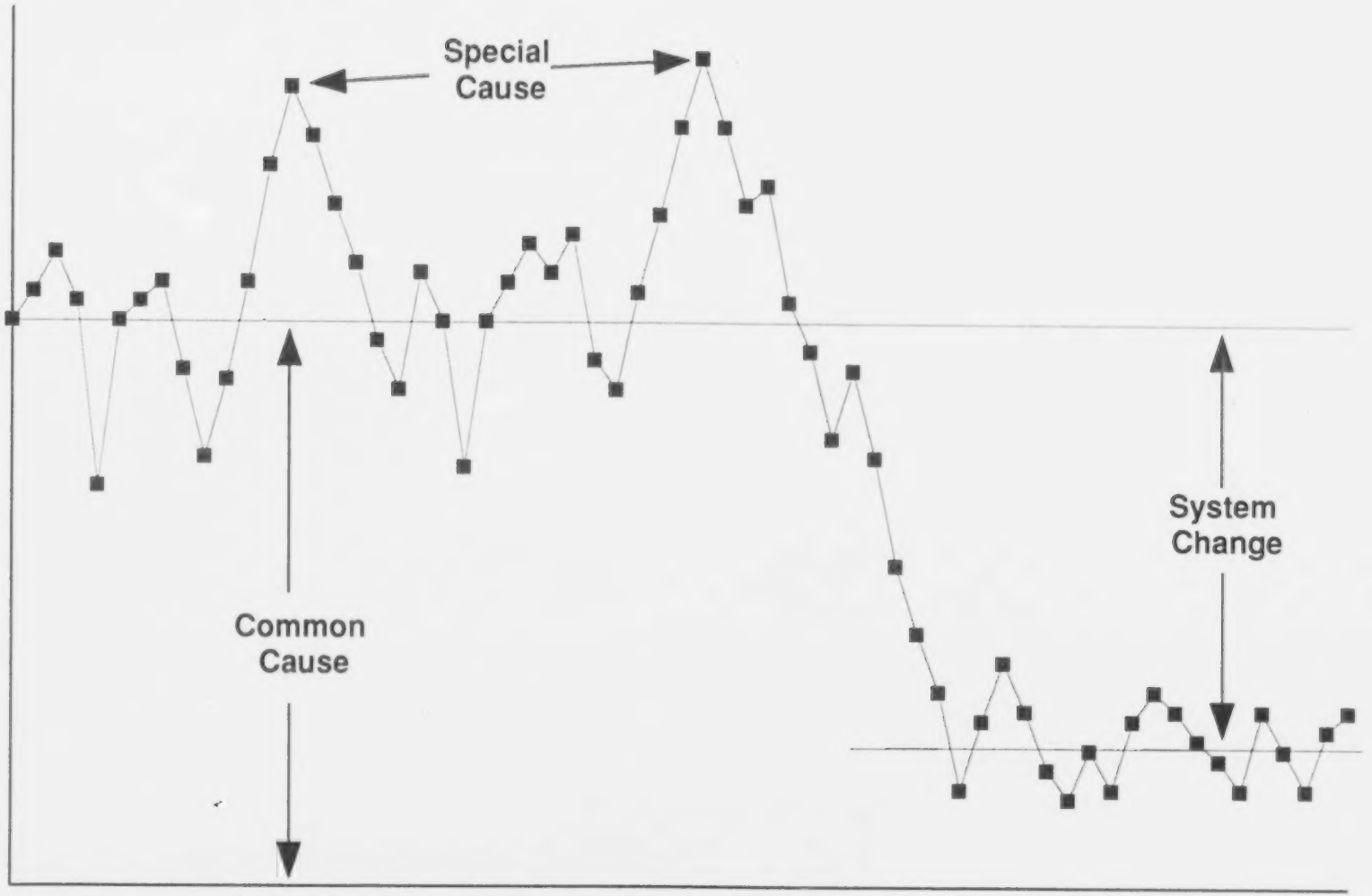

Figure 2 Special-Cause and Common-Cause Variation

Juran (1988, p. 11) discusses the concepts of Figure 2 in an expanded fashion. He calls it the "Juran Trilogy": 1) one begins with quality planning to design a system; 2) the initial level occurs as the system is put into operation and statistical control is attained; and 3) a process of quality improvement is then employed to generate the needed system change. The cycle is constantly repeated.

CONTROL CHARTS

Since much of the above discussion is based upon the concept of a control chart, we pause for a moment to discuss it. After reviewing copies of the Journal of Quality Technology, one becomes convinced that much is still to be said about this concept and its use. Control charts are based upon various statistical distributions, most usually the normal distribution. In the case of the red bead example, a binomial distribution is used. Different numeric data are also used such as: actual values, averages, and ranges. A recent text-book treatment of control charts is given in Ryan (1989) in which he covers some 30 types. These types are based upon combinations of measurements and distributions. Nelson (1987) notes a control chart based upon the cube roots of chi-square values for categorical data.

The usual control chart is designed with a center line (CL) and two control lines with one at 3 sigma above the CL called the upper control limit (UCL) and one at 3 sigma below the CL called the lower control limit (LCL). Tiernan (1991), while he was

relating the use of control charts to a factory floor in the aerospace industry, provided the following suggestions as to when a process is out of control: 1) one point falls outside the 3 sigma control limits; 2) seven successive points are on the same side of the CL; 3) seven successive points show an increase or decrease; 4) two out of three successive points are both on the same side of the CL and outside the 2 sigma zone; 5) four of five successive points are on the same side of the CL and outside the 1 sigma zone; and 6) other nonrandom patterns occur such as trends, cycles, or an unusual spread of points within the control limits.

Control limits are determined from historical data and revised as new data occurs. This revision is based on both data and the assumed distribution. One must know when a special cause occurs and hence when to adjust the limits or not since the very definition of statistical control means that the appropriate values stay within the limits in the expected manner.

APPLICATIONS TO INSTITUTIONAL RESEARCH

Three areas of current university concern and consequently of interest to institutional research on this campus are noted in this section. They are: 1) student retention; 2) application flow and yield; and 3) faculty allocations. Perhaps the reader has already envisioned more such examples of the application of these ideas.

The first, relates to student retention, is a review of some

of the many causes that help determine whether a student chooses to remain at the institution or not. A cause-and-effect diagram is given as Figure 3. As you recall, such a diagram is usually generated in a brainstorming session or reveiw of the literature. It then provides a frame-work for subsequent data gathering and analysis.

The second, related to application flow and yield, is displayed in the format of a Pareto diagram to emphasize the potiential full-time equivalent student (FTES) loss to the university in a given fall term, if applications are closed at the end of each of the months May through October. Even though the FTES are not given in decending order by priority as in the usual Pareto manner, the concept of showing several quantities and the consequent cumulative effect of them is useful. This is exhibited as Figure 4.

The third, related to faculty allocations, is an example that was developed when the campus was changing to a method of allocating faculty positions by the use of student-faculty ratios. The data chosen illustrate one of our departments for which the student-faculty ratio (SFR) was not in control, at least for the years 1978-79 through 1986-87. A new robust regression technique based upon the use of the least median of squares (LMS) due to Rousseeuw and Leroy (1987) was employed in the analysis in addition to the traditional least sum of squares (LSS). Figure 5 provides a line graph of the series of SFR's

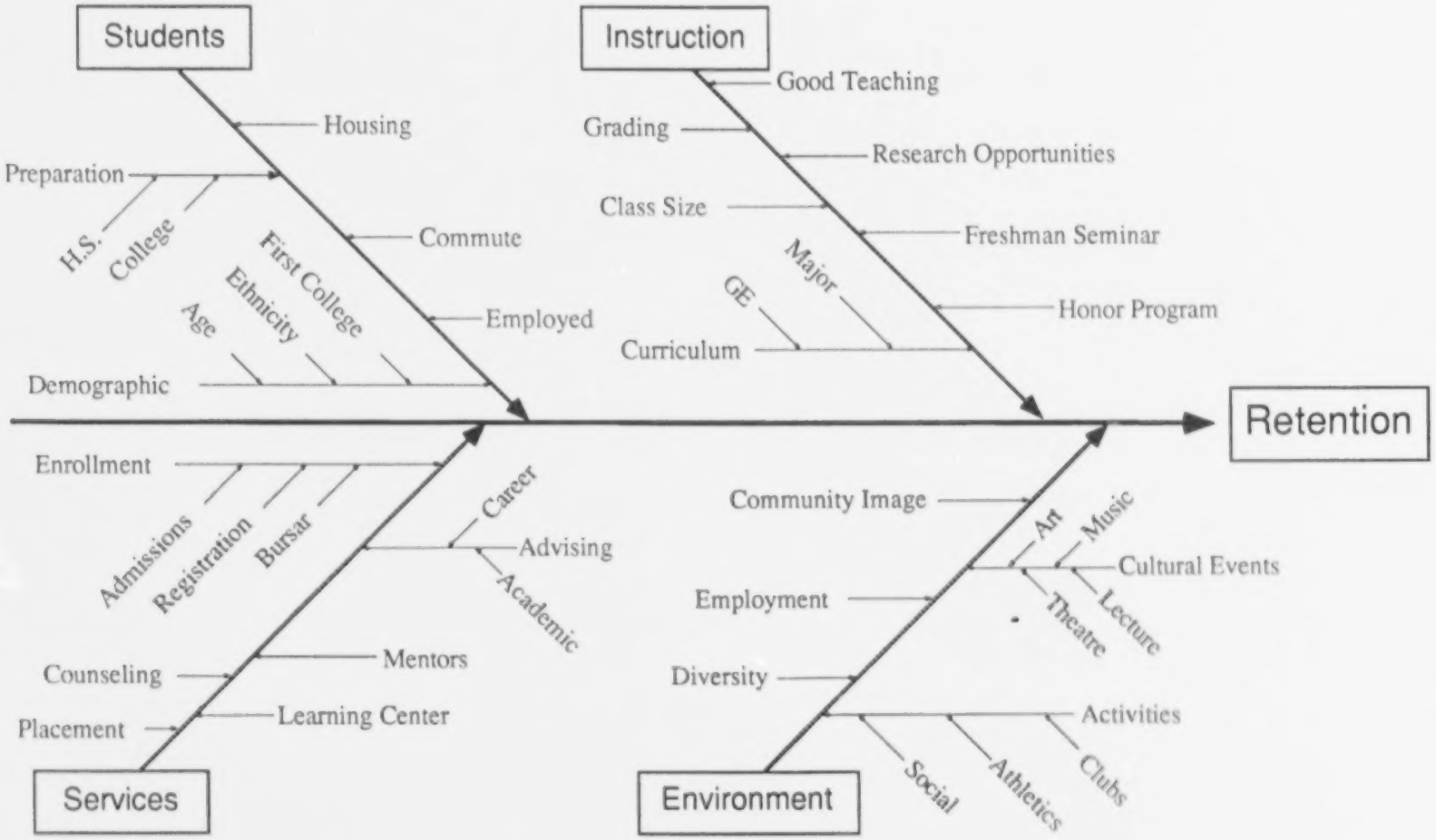

Figure 3 Causes of Student Retention

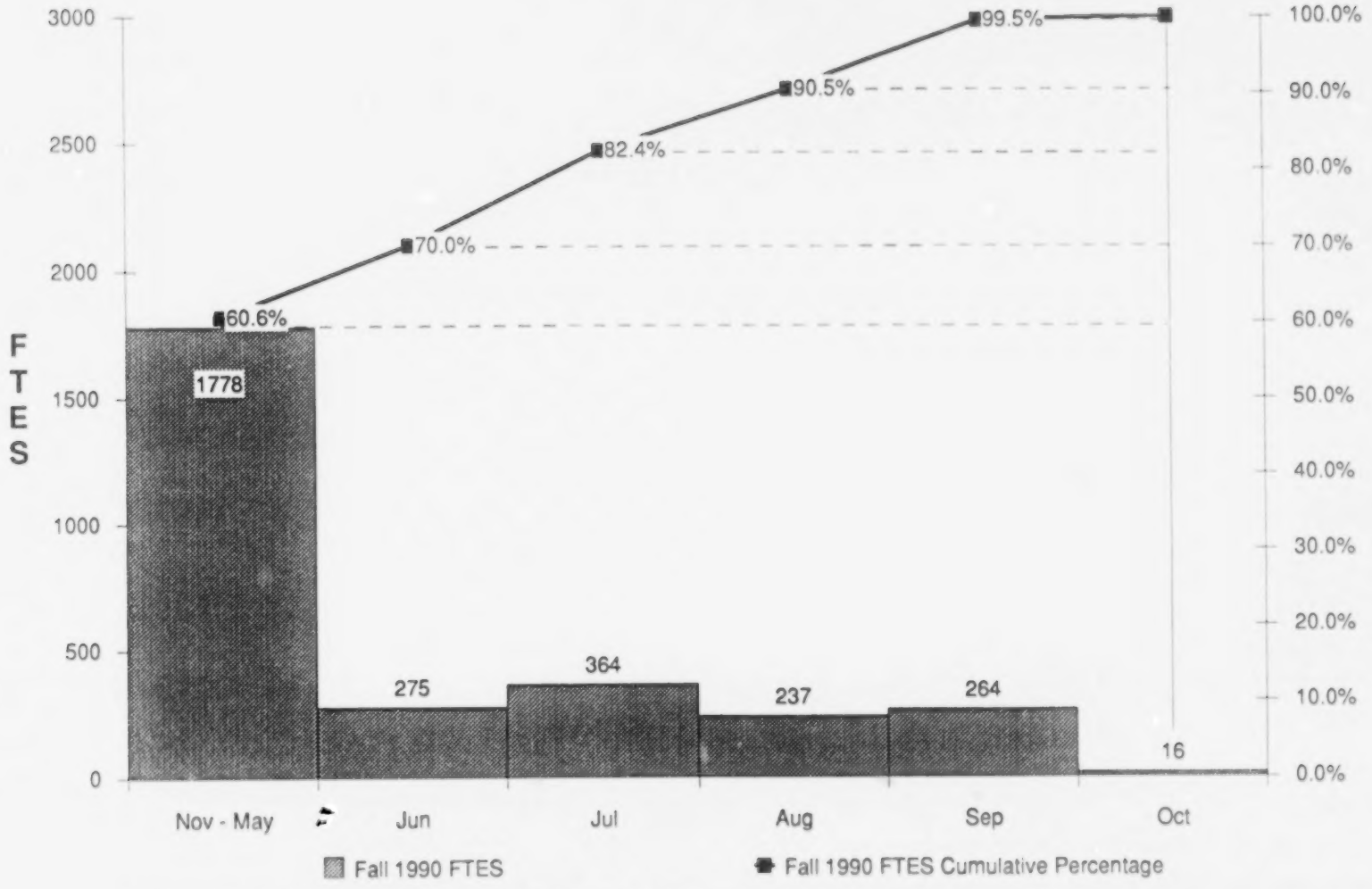

Figure 4 Fall 1990 New Enrollees by Month of Application

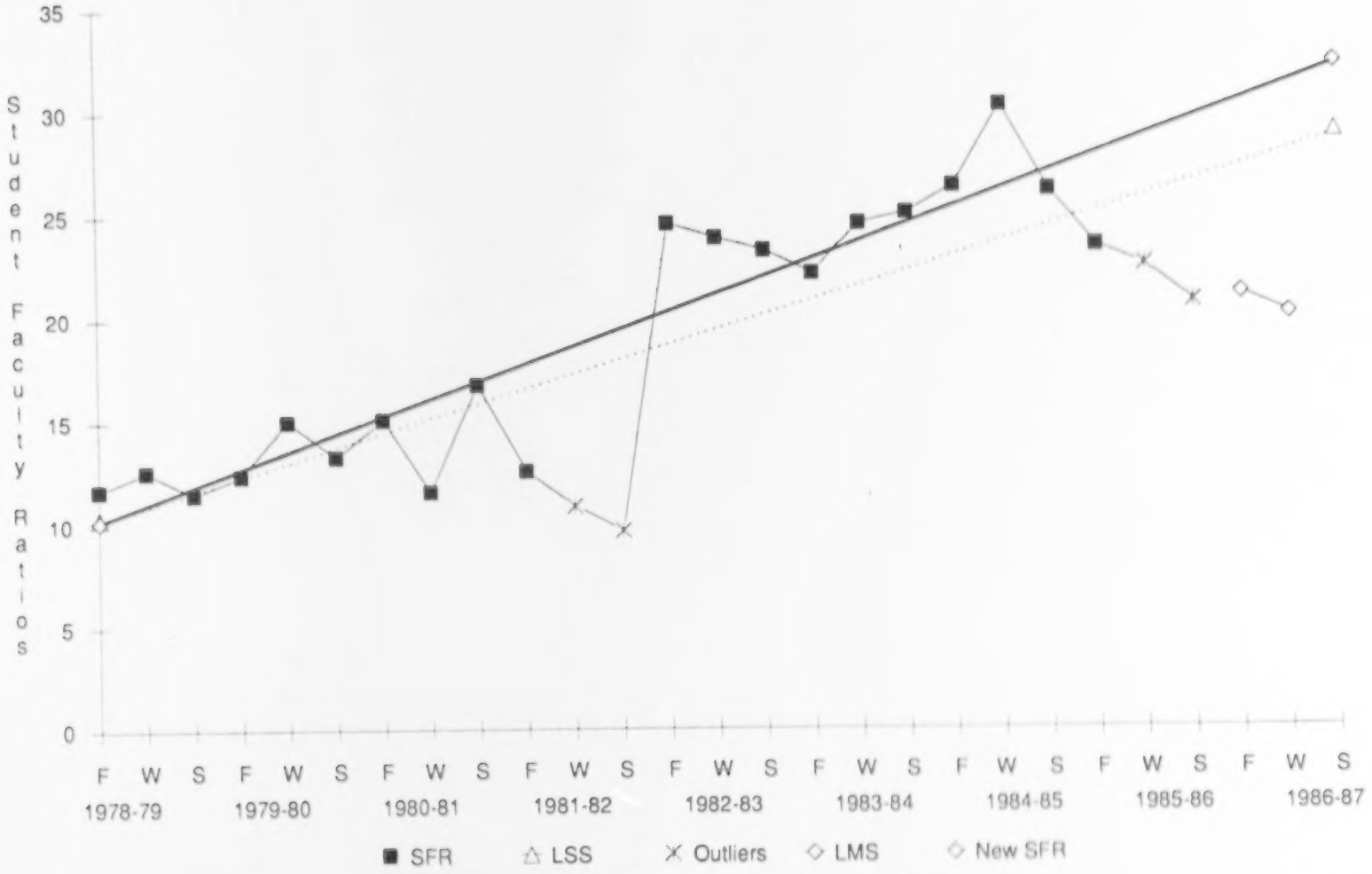

Figure 5 Student Faculty Ratios with Linear Regression

reported by the department with both regression lines for LSS and LMS. The LSS line was determined using the data for the years 1978-79 through 1985-86. The LMS method was applied to the same data but since it has an outlier detection method that excluded the values for the Winter and Spring terms of both 1981-82 and 1985-86, the resulting LMS regression line was different from the original LSS line. The new values that were reported for the two terms of the year 1986-87, indicate that neither line could be used to predict future SFR's. The control chart in Figure 6 was made by determining the 3-sigma range for the LSS residuals. It indicates acceptance of the new data as being in control, but, as expected a similar chart for LMS rejects the new data and all outliers except for Winter 1985-86. A system change occured in 1985-86 when a few large lecture classes were reformated as intermediate size classes thus creating a lower SFR by increasing the number of faculty for the same number of students.

CONCLUSION

By discussing some of the statistical and graphical issues that were indicated by Lawrence Sherr at the 1989 and 1990 AIR forums, we have been introduced to techniques that have application for the pursuit of total quality management (TQM). Some of us will participate in TQM effort, while others of us in institutional research will add these ideas and techniques to our toolkits. It is clear that these techniques draw upon the two current trends in statistical thought and activity, that is, both

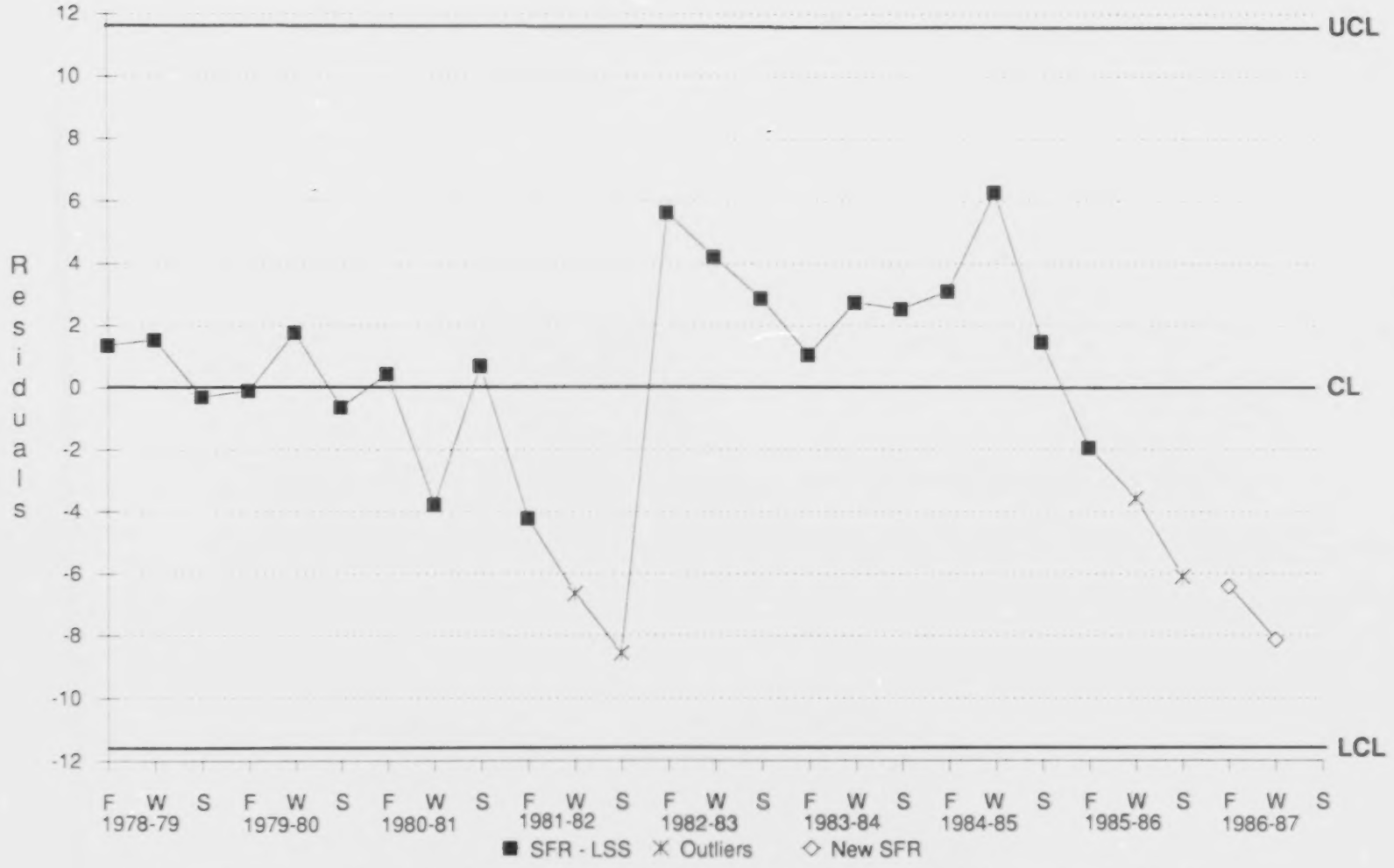

Figure 6 SFR as Residuals versus Least Sum of Squares with Control Limits

confirmatory and exploratory data analysis.

We have considered the cause-and-effect diagram as a graphical technique for developing approaches to the subsequent gathering of data with respect to a given effect or outcome that we wish to understand. We consider the data to be measures of causes that contribute to the outcome. Next, we made the use of Pareto diagram to prioritize or otherwise see the magnitude of various causes affecting an outcome. The discussion of control charts grew out of a consideration of the importance of understanding variation in the processes which we seek to change. The growth and development of an organization in its pursuit of quality requires this understanding. The concept of statistical control was introduced to aid in the handling of special-causes, common-causes and the subsequent system change.

Some applications to areas of current concern to institutional researchers were discussed. It is hoped that these applications and the others cited along with the concepts noted will generate an ever growing list of useful applications.

Other areas of statistical and graphical ideas that occur in TQM include the "New Seven", more on control charts and the use of the discipline of the design of experiments including Taguchi methods. The latter is aimed at determining common-causes.

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